Impact of climate change on culture-based fisheries in seasonal reservoirs of Sri Lanka and the resilience capacities of rural communities

Case study report

Impact of climate change on culture-based fisheries of seasonal reservoirs in Sri Lanka and resilience capacities of rural communities

Executive Summary

Culture-based fisheries (CBF) are an aquaculture activity performed in natural and quasi-natural water bodies. In Sri Lanka two types of reservoirs are used for CBF development. First group of reservoirs is called as minor perennial reservoirs and the other group is called as seasonal (non-perennial) reservoirs. In minor perennial reservoirs, heavy draw-down can be observed in the dry seasons of the year and water retains only for few months in seasonal reservoirs. Water availability of these reservoirs depends on the rainfall received from two monsoons and inter-monsoons. As such, changes in the rainfall pattern due to the climate change impacts caused significant implication on the sustainability of CBF in seasonal reservoirs. Climate change will impact on two main sectors of the CBF; fingerling production and marketing as well as grow out period of the stocked fingerlings in seasonal reservoirs. Therefore, prediction of adverse impacts of climate change, identification of potential impacts and improving resilience capacity of vulnerable communities are indispensable for the sustainability of seasonal reservoir CBF in Sri Lanka.

Present study attempts to identify the changes of reservoir filling patterns in the scenario of climate change and to identify the water retention period of seasonal reservoirs in Sri Lanka. Water availability in selected seasonal reservoirs in five administrative districts was investigated from 1960 to 2010. Daily rain fall data were obtained from closest rain gage station of the Meteorological Department to each reservoir. GIS techniques were used to demarcate catchment characteristics and other useful information such as command area, slope of the catchment etc. A questionnaire survey was carried out to identify the common agricultural practices under each and every reservoir and to determine the irrigation strategies and water release. Also the questionnaire survey attempted to gather information on farmers' experiences of recent climate change implications on the rainfall pattern and water availability for agriculture and CBF. Hydrological model HEC-HMS 3.4 was used together with a water balance model to predict the daily fluctuations of reservoir volumes from 1960 to 2010 in each reservoir.

Frequent fluctuations in reservoir volumes can be observed in all the reservoirs in the sample compared to 1960s. Results revealed that there is high drawdown in the recent past in the seasonal reservoirs compared to 1960s. A forward shifting pattern of drawdown is identified in the recent past due to altered rainfall patterns. These changes have affected the culture season and the duration of the culture period of stocked fingerlings in the reservoirs. Also it has created uncertainty on fingerling production and their market demand. Shifting rainfall may create non-availability of fingerlings at the correct time for stocking. Marketing difficulties can be expected due to shortened culture period. Collectively these impacts may severely affect the sustainability of CBF in seasonal reservoirs.

Corrective measures and policy decisions have to be identified to mitigate the climate change impacts on vulnerable CBF communities in seasonal reservoirs in Sri Lanka. Current study has identified some policy briefs to mitigate the expected negative impacts and consultative workshops were arranged to take farmers perceptions on proposed policy briefs. The proposed policy briefs which were agreed upon by the farmers are (i) climate change has shifted the filling pattern of the seasonal reservoirs so that changes in stocking pattern are needed in

culture based fisheries, (ii) long term simulation of water volumes of seasonal reservoirs and those associated in the cascades should be combined with other models to predict reservoir filling patterns, (iii) farmers are reluctant to stock fish in reservoirs until spilling off has completed, (iv) fish can be stocked in cages in the reservoir and release them after spilling off the reservoir, (v) alternative means of stocking fish fingerlings reared by rural communities should be sought, (vi) improved water management strategies should be adapted by the paddy farming communities to improve the water retention in reservoirs, (vii) identification of alternative stocking sources and (viii) improvement of value addition and product development for harvested fish.

Chapter 1 – Introduction

Culture-based fisheries (CBF) are essentially a form of extensive aquaculture, or a farming practice conducted in small water bodies (generally less than 100 ha) that would not be able to support a subsistence fishery due to a lack of adequate natural recruitment of suitable species (De Silva et al., 2006). Artificial water bodies, which are perennial or non-perennial in nature and built for irrigation purposes, can be used for CBF (De Silva 2003). These water bodies are stocked with suitable species in pre-determined proportions. The stocked fish live and grow in the water body consuming the naturally produced food organisms in it. The fish are harvested at a suitable time or when the water level recedes. A selected community group, who will have ownership of the stock, prepare the water body for stocking, procure seed stock, and care for the stocked fish, in particular by keeping watch over the stock (De Silva et al., 2006; Amarasinghe amd Nguyen, 2009)) .

CBF in Sri Lanka

Non-perennial small reservoirs, which are referred to as seasonal tanks, are often less than 20 ha at full supply level. These tanks usually dry up completely during July–September and fill during the inter-monsoonal rains in December–January. These non-perennial reservoirs of Sri Lanka are highly productive, mainly because of the change in environmental conditions from a terrestrial phase during the dry season to an aquatic phase during the wet months (Amarasinghe, 2006).

Culture-based fisheries in Sri Lanka are mainly developed in non-perennial reservoirs due to their extensive availability and high biological productivity. These reservoirs fill with water only after the inter-monsoonal rains in November–January every year. The water retention period in non-perennial reservoirs is 7–9 months. As such, these reservoirs should be stocked with fish fingerlings in January–February. Accordingly, fingerling rearing, fry rearing and induced breeding of fish should be done at a time so that fish fingerlings are available in January–February (Amarasinghe, 2006).

Agrarian Development Act of 2000 made provisions for community participation in aquaculture in non-perennial reservoirs and culture-based fishery practices has enabled coordination at decision-making levels between the National Aquaculture Development Agency and Department of Agrarian Services, which controls minor irrigation systems including non-perennial reservoirs and small irrigation reservoirs. Aquaculture committees are set up under the farmers' organizations. These committees are responsible for the management of culture-based fisheries. Fingerlings needed for the CBF are produced in the fish breeding centers that are operated by the National Aquaculture Development Agency. Fry-Fingerling rearing is done through community participation (Amarasinghe, 2006).

There are four major steps for sustainable implementation of CBF (Amarasinghe, 2006). They are:

1. Induced breeding of major carps in state owned fish breeding centres;
2. Rearing of post-larvae to fry stage in cement ponds under controlled conditions in state-owned fish breeding centres;
3. Rearing of fry to fingerling size in earthen ponds owned by villagers and net cages installed in perennial reservoirs through community participation; and
4. Stocking of fish fingerlings in non-perennial reservoirs and harvesting after a growth period of 7–9 months for marketing.

To achieve high yields from culture-based fisheries, it is essential to have fingerlings available, suitable non-perennial reservoirs selected and post-stocking management implemented. At the present pace of CBF development, only about 4.5% of the small village reservoirs are utilized (www.naqda.lk; visited on 10.06.2012). However, with the prospects of future CBF development strategies, it is highly unlikely that fingerlings will ever be available in sufficient quantities to stock all non-perennial reservoirs in Sri Lanka (Amarasinghe, 2006).

During the growth period no supplementary feeding or any other sorts of inputs are used. The harvesting is done using seine nets when the reservoir water level is reduced. As the reservoirs used in CBF are small in size and seasonal in nature, no boats or other equipment which uses fuel or energy sources are used.

Case study description

Methodology
Study area
Reservoirs from four administrative districts; Anuradhapura, Kurunegala, Hambantota and Moneragala were selected for the present analysis. List of reservoirs, which have previous experience of doing CBF, were obtained from the National Aquaculture Development Agency of Sri Lanka (NAQDA) and were randomly selected for this study (Table. 1; Figure. 1)

Data collection
Reservoirs were visited and water management practices, cropping pattern and other water uses, problems faced in water management, reservoir spilling and drying patterns, variations in the reservoir filling and drying patterns in the recent past compared to the past etc. were collected by interviewing water controller (locally called "Wel Vidane") of each reservoir and knowledgeable farmers.

A Seasonal Reservoir

A Seasonal Reservoir with aquatic plants

Interviews with the water controller or “Wel Vidane”

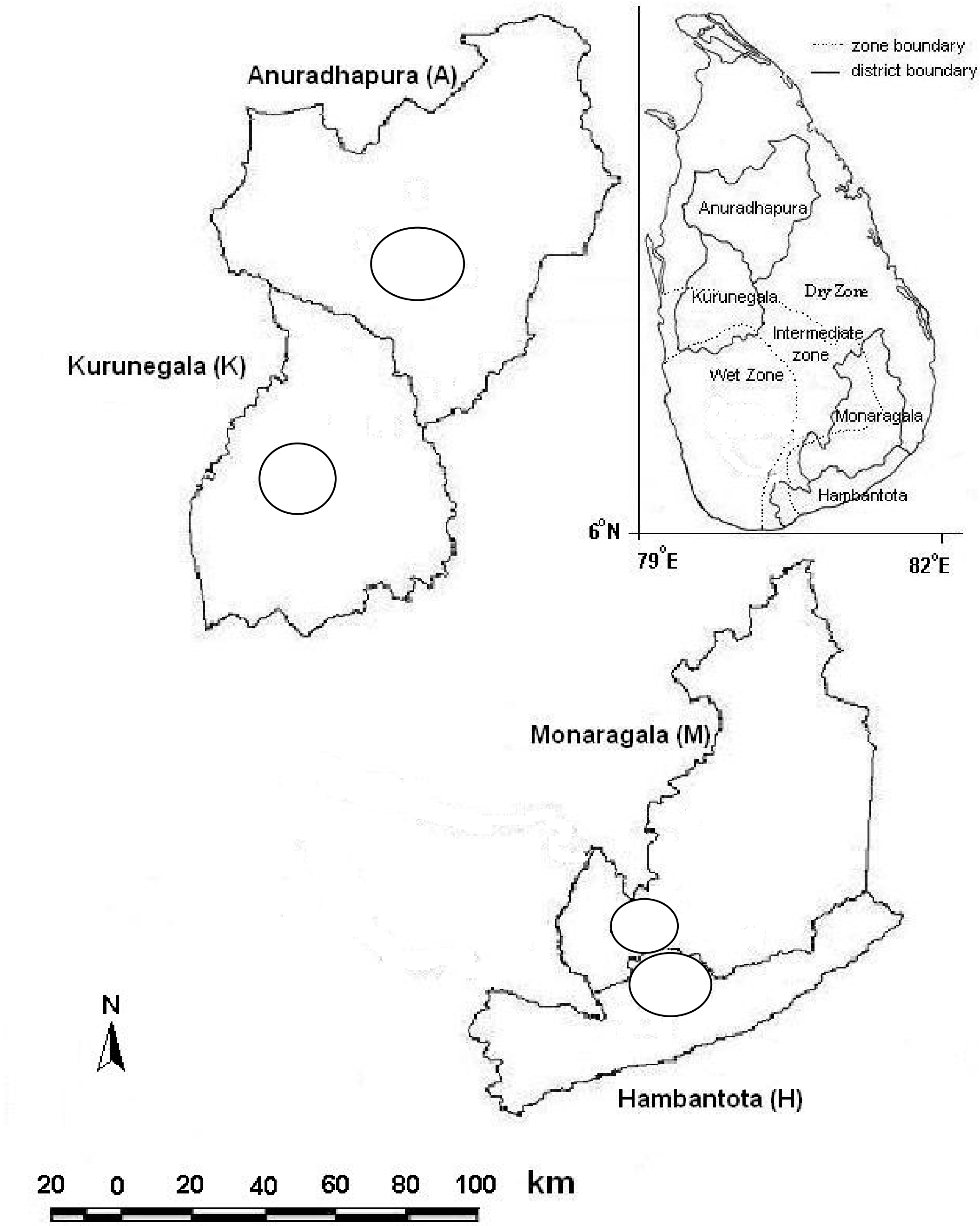

Figure 1. Administrative Districts in which the reservoirs are located, and the locations of reservoirs in each district.

Table 1. Geographic location of selected reservoirs in Anuradapura (A), Kurunegala (K), Hambantota (H) and Monaragala (M) Districts.

Code		Geographic Location	
	Reservoir	N	E
A1	Pahala Sandanankulama Wewa	08^{0} 11′ 03.46″	80^{0} 35′ 55.84″
A2	Ihala Sandanankulama	08^{0} 11′ 02.33″	80^{0} 36′ 31.51″
A3	Karambegama	08^{0} 10′ 36.37″	80^{0} 33′.20.40″
A4	Katugampolagama Wewa	08^{0} 14′ 12.35″	80^{0} 23′ 43.64″
A5	Meegassegama Wewa	08^{0} 10′ 22.20″	80^{0} 31′ 45.00″
A6	Bulankulama	08^{0} 09′ 56.59″	80^{0} 31′ 31.26″
A7	WendaramKulama	08^{0} 09′ 38.38″	80^{0} 31′ 44.08″
A8	Gulupeththa Wewa	08^{0} 08′ 55.76″	80^{0} 31′ 50.82″
A9	Badugama Wewa	08^{0} 09′ 25.00″	80^{0} 31′ 23.69″
A10	Meegaha Wewa	08^{0} 17′ 19.12″	80^{0} 21′ 19.60″
A11	Wandurassegama Wewa	08^{0} 17′ 03.97″	80^{0} 21′ 26.73″
K1	Hindagaha Wwewa	07^{0} 37′ 59.64″	80^{0} 10′ 13.85″
K2	Withikuliya Wewa	07^{0} 42′ 30.65″	80^{0} 08′ 25.77″
H1	Wewegama Wewa	06^{0} 18′ 29.86″	81^{0} 01′ 47.76″
H2	Weli Wewa	06^{0} 20′ 15.75″	81^{0} 01′ 03.40″
H3	Lunuweraniya Wewa	06^{0} 20′ 39.50″	81^{0} 07′ 05.97″
H4	Palujandura Wewa	06^{0} 19′ 19.15″	81^{0} 07′ 16 76″
H5	Madagamkadawara Wewa	06^{0} 21′ 31.28″	81^{0} 09′ 40.52″
H6	Unathu wewa Wewa	06^{0} 21′ 30.62″	81^{0} 09′ 45.31″
H7	Illukkpalassa Wewa	06^{0} 21′ 57.24″	81^{0} 09′ 30.58″
M1	Bodhagama Wewa	06^{0} 25′ 45.31″	81^{0} 05′ 42.44″
M2	Halambagaha Wewa	06^{0} 26′ 01.93″	81^{0} 05′ 23.06″
M3	Galwale Wewa	06^{0} 25′ 58.93″	81^{0} 03′ 28.19″
M4	Nika Wewa	06^{0} 26′ 21.10″	81^{0} 04′ 04.51″
M5	Meegas Wewa	06^{0} 27′ 16.08″	81^{0} 04′ 43.32″

Hydrological components in the catchment areas were derived from landuse maps of 1:50,000 scale. Catchment landuse, the flow networks, and the gradient of the catchment were derived from the same maps using GIS techniques. Verification of the land use patterns was done by visiting the catchments of reservoirs. Areas at the full supply level of some of the reservoirs were measured with GPS (Trimbel GeoExplorer 3; Trimbel Navigation Ltd., California USA) and areas of the other reservoirs were derived using satellite remote sensing. Area of some reservoirs (Table 2), which had cloud effects in satellite images were derived with 1:50,000 land use maps using GIS (Table 2). Depths were measured by visiting the reservoirs. Water levels at the spills were measured as the maximum water level of the reservoir (Table 2).

Water losses from reservoirs were considered to occur in three different ways i.e., irrigation, diversions for cultivations (mainly for paddy), seepage and percolation and evaporation/evapotranspiration. Crop data (irrigation intervals, durations and types of crops grown in the command area) were obtained from the water controller of each of the study reservoir. Base flow of the catchments was considered as negligible in the dry period as all streams were seasonal in nature. Imperviousness of forests was considered as zero and it was estimated according to the nature of other land uses if there are no specific rocky land areas. Average seepage and percolation was assumed as 4 mm day^{-1} and monthly pan-evaporation of different regions was calculated based on the pan evaporation data collected from the meteorological department based on Allen et al. (1998). Rainfall data were obtained from the Meteorological Department of Sri Lanka. Rainfall of the closest rainfall stations to the reservoirs was considered for the hydrological simulation (Table 3). Daily rainfall data from January 1961 to February 2011 were used in the present analysis.

Hydrological Modelling

The major constrain in studying the climate change scenario in CBF would be unavailability of water levels or water volumes in the reservoirs. Therefore, in this analysis, an attempt was made to use a hydrological model HEC-HMS 3.0.1 to generate flows into non-perennial reservoirs from 1961 to 2011. HEC-HMS 3.0.1 considers the watershed characteristics together with rainfall to simulate runoff from the catchments.

Out of the components in the HEC-HMS, Snyder's unit hydrograph as the transform method, SCS curve number method as the loss method, constant monthly as the baseflow method were used. For precipitation calculation, specified hyetograph was used with monthly average evaporations. As the catchments used in present study are small, precipitation over the total catchment was considered as uniform and the daily rainfall of the closest gauge station of the Meteorological Department was used to simulate the flow (Table 3).

Reservoir volumes were calculated using hydrological modelling for the period 1961 to 2011. Calculation was performed in two main domains; i.e. calculation of the catchment runoff and calculation of actual volume of reservoir by considering gains and losses of the reservoir. Reservoirs in the upper cascade area act as water holding units in the catchment. Therefore, the reservoirs above in the catchment were considered as points which collected water and the spill-outs of those reservoirs were added to the water yield generated from micro-catchment of following reservoir (Figure 2).

Table 2. Reservoir area at full supply level and maximum depth of selected reservoirs.

Code	Reservoir	Area at Full supply level (ha)	Maximum depth (m)
A1	Pahala Sandanankulama Wewa	21.8	3.2
A2	Ihala Sandanankulama	8.8	3.65
A3	Karambegama	9.3	2.5
A4	Katugampolagama Wewa	16.7	2.44
A5	Meegassegama Wewa	29	3.54
A6	Bulankulama	10.4	3.64
A7	WendaramKulama	6.6	3.65
A8	Gulupeththa Wewa	1.5	3.0
A9	Badugama	2.5	2.4
A10	Meegaha Wewa	11.1	2.44
A11	Wandurassegama Wewa	5.9	2.74
K1	Hindagaha Wewa	2.9	3.0
K2	Withikuliya Wewa	6.9	2.65
H1	Wewegama Wewa	18.9	3.1
H2	Weli Wewa	5.7	1.97
H3	Lunuweraniya Wewa	10.8	2.42
H4	Palujandura Wewa	4.9	2.08
H5	Madagamkadawara Wewa	16.7	3.3
H6	Unathu wewa Wewa	13.1	3.0
H7	Illukkpalassa Wewa	9.2	2.7
M1	Bodhagama Wewa	13.4	1.96
M2	Halambagaha Wewa	2.4	1.96
M3	Galwale Wewa	15.7	2.37
M4	Nika Wewa	11.7	1.69
M5	Meegass Wewa	21	2.82

Table 3. Different rain gage stations and agro-ecological zones for selected reservoirs

Code	Reservoir	Rain gage station	Agro-ecological zone
A1	Pahala Sandanankulama Wewa	Maradankadawala	DL1b
A2	Ihala Sandanankulama	Maradankadawala	DL1b
A3	Karambegama	Maradankadawala	DL1b
A4	Katugampolagama Wewa	Maradankadawala	DL1b
A5	Meegassegama Wewa	Maradankadawala	DL1b
A6	Bulankulama	Maradankadawala	DL1b
A7	WendaramKulama	Maradankadawala	DL1b
A8	Gulupeththa Wewa	Maradankadawala	DL1b
A9	Badugama Wewa	Maradankadawala	DL1b
A10	Meegaha Wewa	Maradankadawala	DL1b
A11	Wanduressegama Wewa	Maradankadawala	DL1b
K1	Hindagaha Wwewa	Mediyawa	DL1b
K2	Withikuliya Wewa	Mediyawa	DL1b
H1	Wewegama Wewa	Sooriyawewa	DL1b
H2	Weli Wewa	Sooriyawewa	DL1b
H3	Lunuweraniya Wewa	Bandagiriya	DL5
H4	Palujandura Wewa	Bandagiriya	DL4
H5	Madagamkadawara Wewa	Bandagiriya	DL1b
H6	Unathu wewa Wewa	Bandagiriya	DL1b
H7	Illukkpalassa Wewa	Bandagiriya	DL1b
M1	Bodhagama Wewa	Thanamalwila	DL1b
M2	Halambagaha Wewa	Thanamalwila	DL1b
M3	Galwale Wewa	Thanamalwila	DL1b
M4	Nika Wewa	Thanamalwila	DL1b
M5	Meegas Wewa	Thanamalwila	DL1b

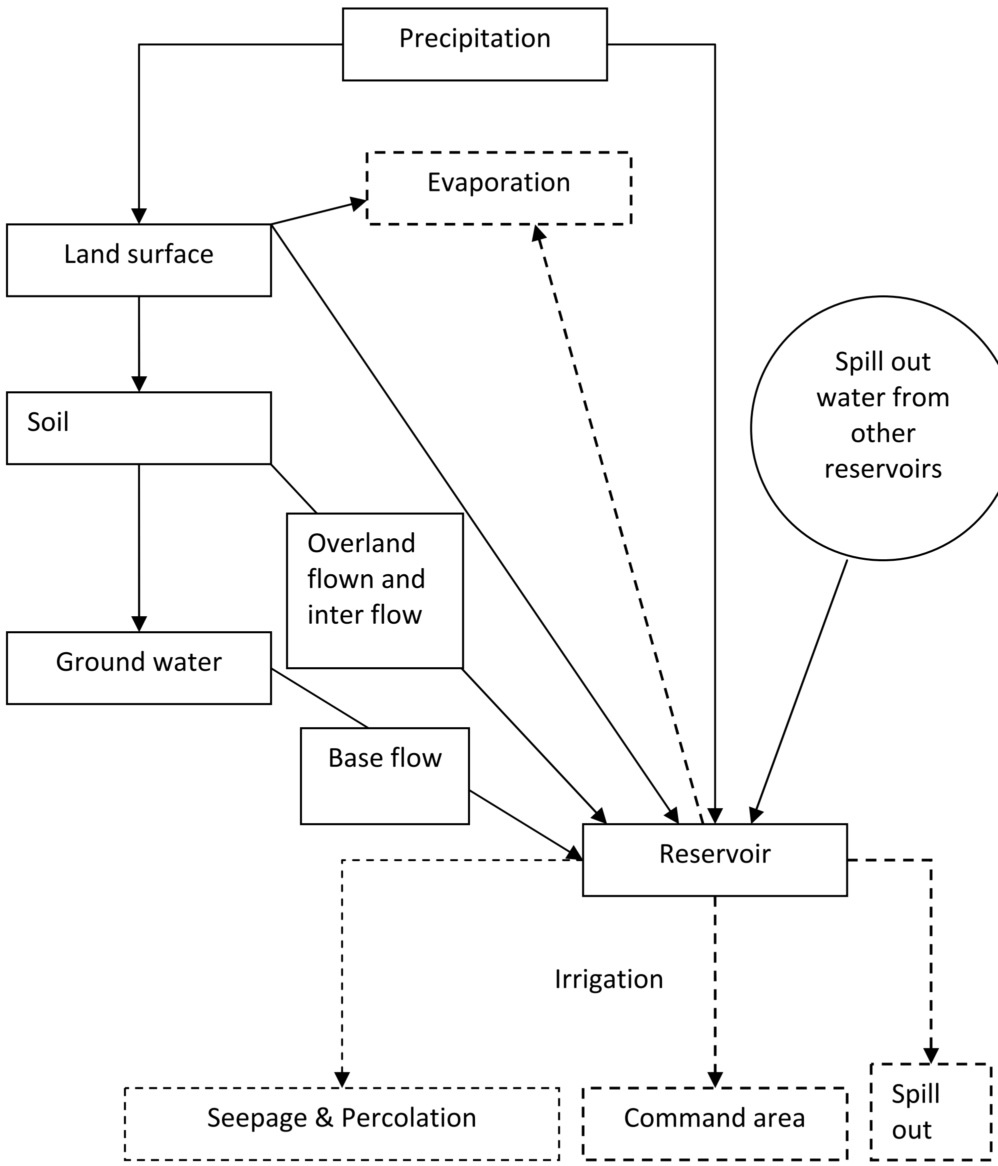

Figure 2. Schematic diagram of water flow of a reservoir located in a cascade system. Continuous lines represent the water gain into the reservoir and broken lines represent the water loses from the reservoir.

Water balance modelling

The total runoff for the catchment was generated using the hydrological simulation model. Based on the generated runoff, volume in the reservoir was calculated. Water gain and losses (as explained in Figure 2) were considered as follows;

$$V_i = [(V_i - 1) + (RO_i)] - [EP_i + SP_i + IR_i], \qquad (0 \le V_i \le V_{max})$$

where, V_i is reservoir volume in i^{th} day (m^3), RO_i = runoff volume in i^{th} day (m^3), EP_i is evaporation loss in i^{th} day (m^3), SP_i is seepage loss and percolation loss in i^{th} day (m^3), IR_i is irrigation volume in i^{th} day (m^3) and V_{max} is maximum volume of reservoir (m^3).

Evaporation losses occur from the water surface and causes volume changes to the reservoir volume. The volume lost due to evaporation varies with the reservoir area and the total evaporation loss was calculated per day as follows:

$$EP_i = \left(\frac{V_i}{D_i}\right) x\, E_p$$

where, EP_i is evaporation loss in i^{th} day (m^3), V_i is volume of reservoir in i^{th} day, D_i is average water depth (m) and E_p is pan evaporation (m).

Irrigation diversions were calculated per day as follows:

$$IR_i = A_i \text{ x } CWR \text{ x } CP$$

where, IR_i is irrigational loss (m^3), A_i is command area (m^2), CWR is crop water requirement (m day^{-1}) and CP is cropping period (days).

Volume (V_i) of the reservoir can be calculated until the volume reaches the maximum level (V_{max}). When the volume reaches its maximum, the reservoir starts to spill out. The spill out volume (SV_i) was calculated as follows:

$$SV_i = [(V_{max} + RO_i) - (EP_i + SP_i + IR_i)] - \mathbf{V}_{max} \qquad (\mathbf{V}_i + \mathbf{RO}_i \geq \mathbf{V}_{max}, \mathbf{Vi} = \mathbf{V}\, max)$$

The spill out volume is an input to the next reservoir in the cascade (Figure 2).

Project justification

It is evident that perceptible changes on a global and regional scale are proceeding in earth's climate. The observed changes include an increase of air temperature, regional monsoon variation, frequent droughts and a regional increase in severe storm incidence in coastal states. This may have impacted on the inland aquatic resources and their fisheries (Vass et al., 2009).

Rural Sri Lanka stands on the agriculture-based economy with a long history of over 2000 years. The living example of the agricultural economy is the unique irrigation system developed by forefathers of the country. From the ancient period to present the main objective of the network of the irrigation system is providing water for paddy lands. Since early 1980s, small village reservoirs have been used for Culture-Based Fisheries (CBF) which essentially involves stocking of hatchery reared fish fingerlings in natural or quasi-natural water bodies for enhancing fish production. CBF is a secondary use of existing water resources benefiting communities in the rural areas. The unique feature of CBF is that it is not a competitor with traditional paddy cultivation and as such, it has become increasingly popular among the rural farmer communities.

The rural agriculture activities and CBF in Sri Lanka are based on the two rainy seasons during April-May and October-December. When the development of CBF is carried out in seasonal reservoirs, one of the major requirements would be to make available fish fingerlings for stocking at the correct time coinciding reservoir filling following intermonsoonal rains in October-December (Figure 3). The time of the onset of the rainfall as well as the duration also alter the traditional crop calendar of farming. Similarly, it can be expected that CBF calendar would also be affected by changes in rainfall patterns. In the recent decades, the rainfall has undergone changes and as a result, water scarcity and excess water have become a recurrent problem in crop production in Sri Lanka and further Jayawardena et al. (2005) has shown the decreasing trend of rainfall in 13 rainfall stations over recent 50 years. Changes in rainfall pattern were observed in Kerala, India as a result of climatic change (Pal and Al-Tabbaa, 2009).

Months																		
M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
Induced Breeding of Major Carps		Fry Rearing		Fingerling Rearing			Storing in Reservoirs					Culture Period				Harvesting		

Figure 3. Correct timing of culture-based fisheries in seasonal reservoirs of Sri Lanka. Rainy seasons (N, D, J) are shaded. Adopted from Amarasinghe and Weerakoon (2009).

Induced breeding of major carps, rearing of post larvae to fry stage and then to fingerling stage are major pre-stocking activities associated with CBF (Figure 4). In order to produce fish fingerlings for stocking in seasonal reservoirs, it is necessary to predict the rainfall pattern. The absence of sufficient rainfall or shifting of intermonsoonal rains due to climate change might make it difficult to predict timing of reservoir filling to perform fish stocking. Also, gonadal maturity of major carps is seasonal, and evidently is influenced *inter alia* by rainfall patterns. As a result, rural fish farmers might encounter significant financial losses at every stage of CBF. Therefore, there should be a mechanism through which rural communities engaged in CBF can adapt to climate change to overcome unexpected economic losses. Reliable prediction of water availability in village reservoirs is therefore a useful approach for improving resilience of rural communities to climate change.

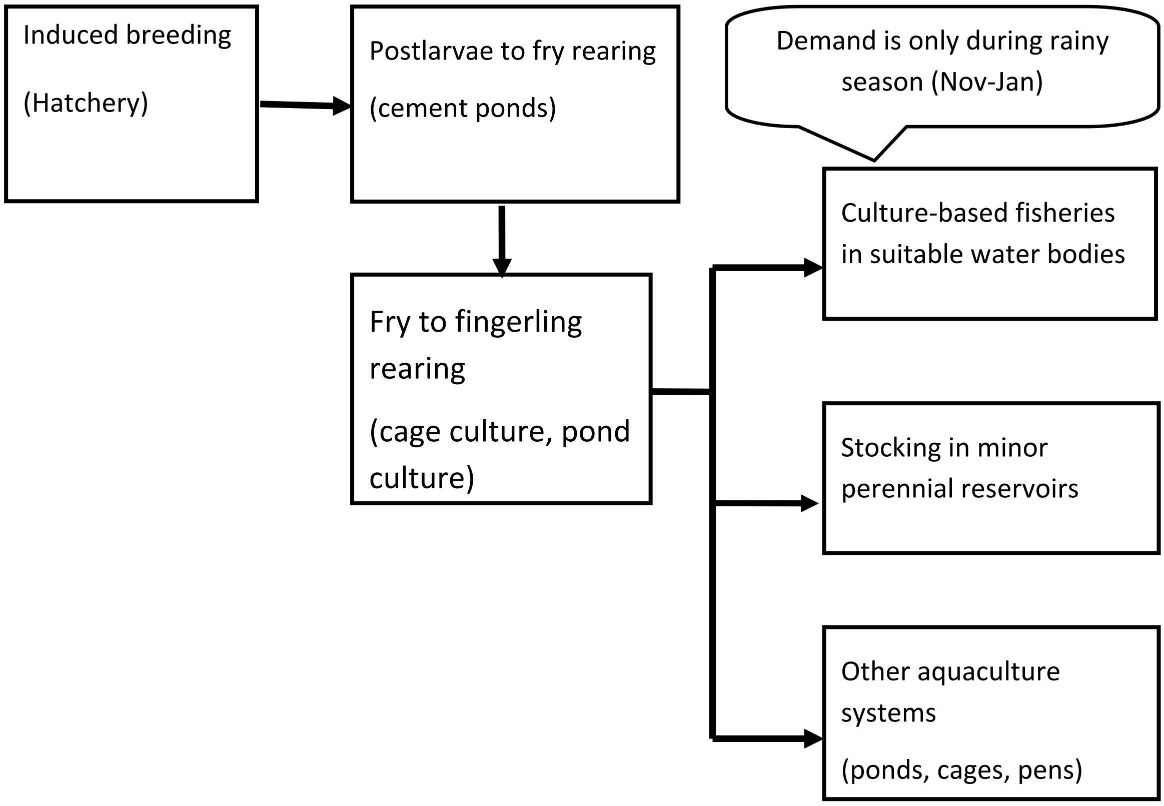

Figure 4. Various options for carp aquaculture in Sri Lanka.

Project objectives and activities of the project
In this project it is aimed at investigating the potential impacts of climate change on CBF in selected small village reservoirs and minor perennial reservoirs.

Activities of the project are given in detail under the methodology followed.

Partners and funding
Partners
1. Department of Zoology, Faculty of Science, University of Kelaniya
2. Department of Aquaculture and Fisheries, Faculty of Livestock, Fisheries and Nutrition, Wayamba Universitity of Sri Lanka, Kuliyapitiya.
3. School of Life and Environmental Sciences, Deakin University, Victoria, Australia

Research Team

a. Dr. M.M.M. Najim (Principal investigator), Department of Zoology, University of Kelaniya;
b. Prof. U.S. Amarasinghe, Department of Zoology, University of Kelaniya;
c. Dr. W.M.H.K. Wijenayake, Department of Aquaculture and Fisheries, Wayamba University of Sri Lanka, Makandura, Gonawila (NWP). Sri Lanka
d. Prof. Sena S. De Silva, School of Life and Environmental Sciences, Deakin University, Victoria, Australia

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Chapter 2 – Climate change prediction (2020 and 2050 scenarios)

Climate change – predicted scenarios (seasonal change, gradual change, Extreme events)

De Silva et al. (2007) predicted climate change to 2050s employing two scenarios, one representing heterogeneous, regionalised, market-led world, with high population growth, leading to a rapid increase in atmospheric carbon dioxide levels (A2) and the other as a regionalised future with more moderate population growth and more concern for the environment and local sustainability, and a slower rate of increase in atmospheric carbon dioxide (B2). Spatial variation of rainfall in Sri Lanka during the wet season (October–February) (Maha) for the baseline (1961-1990), and predicted for the A2 and B2 2050 climate change scenarios are given in Figure 5. The maps show a decrease in rainfall across most of the country. Their results suggest that during the wet season, average rainfall decreases by 17% (A2) and 9% (B2), with rains ending earlier, and potential evapotranspiration increasing by 3.5% (A2) and 3% (B2). The reductions in wet season rainfall combined with higher temperatures will lead to higher irrigation requirements. Consequently, the average paddy irrigation water requirement increases by 23% (A2) and 13% (B2). Increased paddy water requirements will stress the seasonal reservoirs more and the increased demand by paddy will decrease the water levels in the reservoirs quickly reducing the culture period of the CBF.

There is general consensus among future projections that Sri Lanka will become increasingly warmer during the twenty-first century (2100), although the projected magnitude of temperature increase differs from study to study (Eriyagama et al., 2010). Warming projected by the IPCC during the Northeast Monsoon (NEM) is more than during the Southwest Monsoon (SWM) (Cruz et al. 2007). Kumar et al. (2006) and Islam and Rehman, (2004) used different models but confirm projections made by the IPCC of higher warming during the NEM and lower warming during the SWM. Basnayake and Premalal (2008) also suggests higher increases (+2.9 °C) in the NEM season and lower increases (+2.5 °C) in the SWM season. Seo et al. (2005) stated that with warming, the already dry regions (the Northern and Eastern provinces), are expected to lose large portions of their current agriculture. NEM is the main season in which the seasonal reservoirs get filled. Based on these studies, with the increase in the NEM temperatures, the evaporation and evapotranspiration will be increased increasing the paddy water requirement and increasing water loss from reservoirs by evaporation and evapotranspiration through macrophytes. These changes together will decrease the water retained in the seasonal reservoirs and / or the duration of water retention in the reservoirs decreasing the culture period.

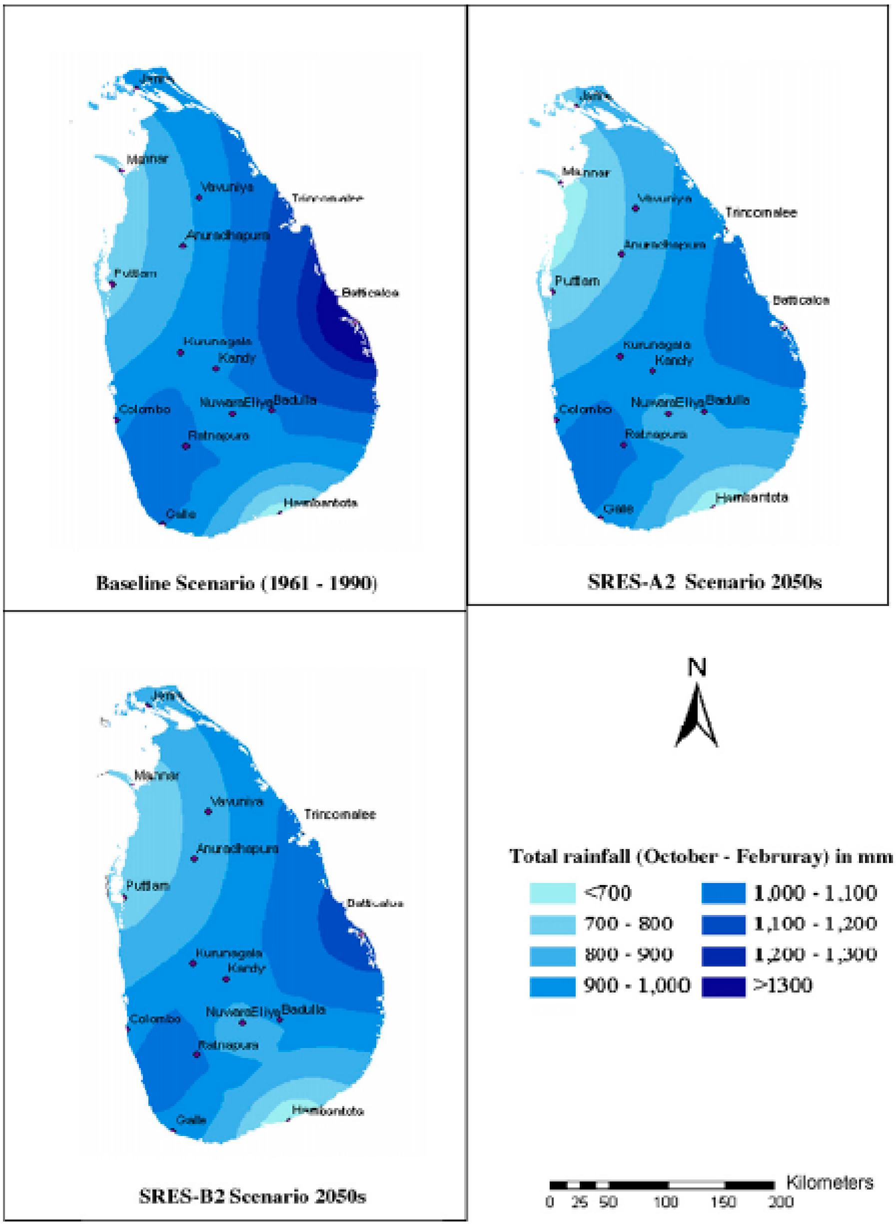


Figure 5. Spatial variation in rainfall from October to February for the baseline (1961–1990) and A2 and B2 scenarios for 2050s (De Silva et al., 2007).

Basnayake and Vithanage (2004), envisage an increase in rainfall during the SWM (the season when rainfall is confined mainly to the wet zone) and a decrease in NEM rainfall (the season when the majority of the dry zone receives rainfall) for a range of IPCC scenarios (A1, A1FI, B1, A2 and B2). De Silva (2006) further elaborates that these changes by the 2050s (with reference to the period 1961-1990) will be of the following magnitudes: MAP – increase by 14% for A2 and 5% for B2; NEM rainfall – decrease by 34% for A2 and 26% for B2; SWM rainfall – increase by 38% for A2 and 16% for B2. The reduction in the NEM rainfall will influence the filling (pattern and magnitude) of the seasonal reservoirs. This will influence the stocking and culture period of the CBF.

De Silva (2006) projected an enhanced rainfall in the wet zone, northwestern dry zone and southwestern wet zones and reduced rainfall in other dry zone areas (such as Anuradhapura, Batticaloa and Trincomalee), and increased rainfall (2%) in the intermediate zone; all by the

2050s for scenario A2. Ashfaq et al. (2009) suggested an increased rainfall during the SWM in western Sri Lanka (which is generally wetter than the east) and decreased rainfall in the eastern part. This spatial trend has also been noted by De Silva (2006) and Basnayake and Vithanage (2004). Jayatillake and Droogers (2004) project a somewhat wetter situation, with simultaneously more variation in annual precipitation in the Walawe Basin. Impact of climate change on water resources is expected to be borne by the northeastern and eastern dry zone of the country; they may become even drier by the 2050s (De Silva, 2006). The changes in rainfall and temperature, together with other climatic factors, may increase the average reference evapotranspiration and maximum annual potential soil moisture deficit (PSMDmax) across the country by the 2050s (De Silva 2006; De Silva et al. 2007). These predictions will also have negative impacts on CBF. In the areas where the rainfall is predicted to reduce will face problems on reservoir filling and duration of the culture period while in the Northwestern part of the country and Walawe basin might phase problems of harvesting due to prolonged filling of the reservoirs.

Impacts of climate change on the weather in Sri Lanka

Increasing temperature

- Air temperature in Sri Lanka has increased by 0.64°C over the past 40 years and 0.97°C over the last 72 years, which revealed a trend of 0.14°C per decade. However, the assessment of a more recent time band of 22 years has shown a 0.45°C increase over the last 22 years, suggesting a rate of 0.2°C per decade.
- Consecutive dry days are increasing in the Dry and Intermediate Zones.
- Ambient temperature (both minimum and maximum) has increased.
- The number of warm days and warm nights has increased, while the number of cold days and cold nights has decreased.

Rainfall variability

- The precipitation patterns have changed, but conclusive trends are difficult to establish.
- A trend for rainfall decrease has been observed historically over the past 30-40 years, but this is not statistically significant.
- There is a trend for the increase of one day heavy rainfall events.
- An increase in the frequency of extreme rainfall events are anticipated, which would lead to more floods.

Drought

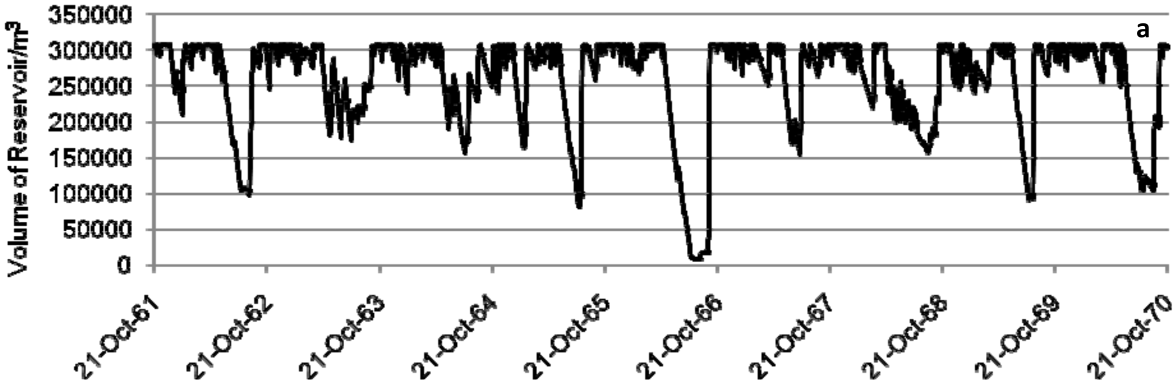
- The increased frequency of dry periods and droughts are expected.
- The general warming trend is expected to increase the frequency of extreme hot days.

Risks faced by CBF due to climate change

- **Frequent fluctuation of reservoir volume**

Frequent fluctuation of water levels in seasonal reservoirs in recent past can be observed form most of selected reservoirs for this study. For an example, Figures 6 a and b show the changes of volume of Wawewgma Wewa reservoir in Hambantota district in the period of 1961-1970 and 2001-2010, respectively. Graphs indicate the frequent drying off of the reservoir in recent decades.

(a)



(b)

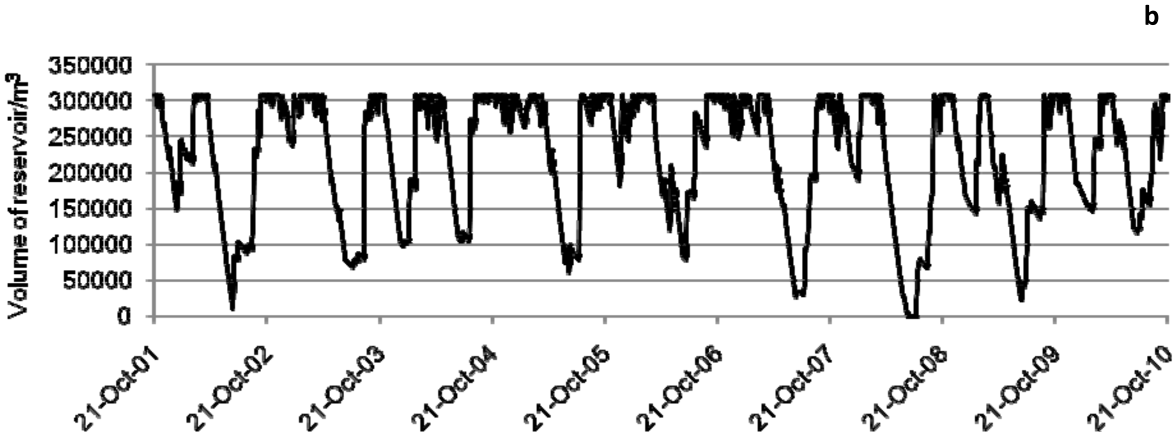


Figure 6. Fluctuation of reservoir volume of Wewegama Wewa reservoir in Hambantota district. (a) and (b) indicate the fluctuation of reservoir volume from 1961 to 1970 and 2001 o 2010, respectively.

- **Increased drawdown of reservoirs**

Figure 7 indicates comparatively high drawdown of water level from 2001 - 2010 compared to 1960s. Among all the reservoirs the drawdown volume has been increased compared to the volume of 1960s. Although the drawdown volumes of the reservoirs have been increased, reservoirs in Anuradapura and Kurunegala have less drawdown compared to reservoirs in Hamabamtota district. Several authors have revealed that the reduction of rainfall over the country in recent past (de Silva 2009; Ranatunge et al., 2003). Eriyagama et al. (2010) indicated the reduction of annual rainfall over the country from the period of 1961 to 1990 compared to the period of 1931 to 1960 from 144 mm. As such the increased drawdown of the volumes in reservoirs would be expected with the climate change scenario.

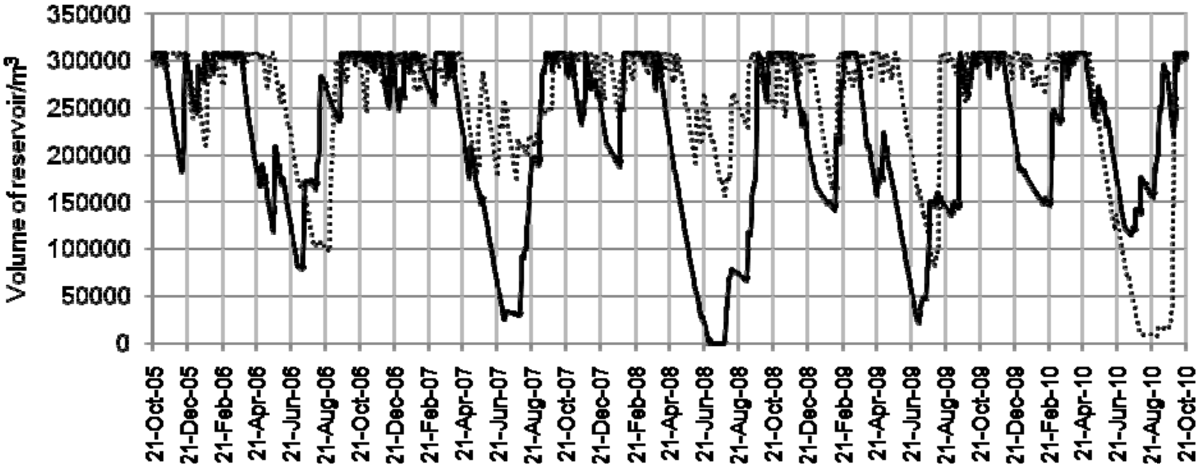


Figure 7. Increased drawdown and Shifting of drawdown period of Wewegama Wewa in 2005-2010 compared to 1965-1970. Dotted line indicates the fluctuation of reservoir volume in 1965-1970.

- **Shifting of drawdown**

Shifting of the drawdown period can be observed from the reservoirs in last decade compared to 1960s. Figure 4, for an example, indicates the forward shifting of drawdown in the period of 2005-2010 in Wewegama Wewa reservoir in Hambantota district. This shifting has observed in most of the reservoirs in the sample. The shifting of drawdown has a potential risk on the duration of the culture period of the stocked species in non perennial reservoirs. Highly shifted drawdown periods can be observed in the Wewegama Wewa reservoir in Hambantota district Figure 7. Shifting of one month period in 2005 to 2010 can be identified from the Wewegama Wewa reservoir compared to 1960s. 1960s the draw down had started in March and it has been shifted to March in period of 2000 to 2010.

Impacts

Frequent fluctuation of reservoir volume, increased drawdown of reservoirs and shifting of drawdown have created uncertainty of water availability in reservoirs and caused curiosity of stocking fingerlings. This issue also alters culture period (shortened culture period and/or inability of harvesting due to reservoir filling).

Increased drawdown and the shifting of the drawdown period in seasonal reservoirs would impact on the sustainability of the CBF in seasonal reservoirs. Early draw down leads to shortened culture period causing marketing difficulties and low production. Frequent fluctuations of reservoir volume potentially create the stressful conditions to stocked fish species and may increase the mortality due to diseases, high vulnerability to predators. This can increase the susceptibility of stocked fish for poaching. The frequent fluctuation can be created intolerable water quality extremes causing massive deaths of stocked species. Therefore, identification of strategies to improve the resilience of vulnerable fish farming communities to climate change impacts has prior important for the sustainability of CBF in seasonal reservoirs.

Climate change also can cause the following impacts.

- Increased flooding due to increasing number of high rainfall events will affect inland aquaculture and capture fishery due to pollution, sedimentation and any adverse changes in water quality parameters of surface water bodies (mainly tanks) that sustain this fishery.
- Drought would lead to lower yields in seasonal tanks, and thereby have severe impacts on the inland fishery as investments for aquaculture may not yield adequate returns.
- Reduced production from the inland fishery would affect rural nutrition and incomes for those dependent on this activity.
- Decreased primary productivity caused by temperature anomalies can affect the abundance of species higher up in the food chain in the long-term.
- Rising temperatures may also lead to greater evapotranspiration and evaporation in irrigation tanks which may have impacts on the inland fishery and aquaculture.

Chapter 3 – Resource use bench marking

Culture based fisheries is predominantly dependent on the food available in the water body. There is no formulated feed used in the CBF systems in Sri Lanka. This is an extensive aquaculture practice, which depends on minimum inputs. To maximise the use of feed available in the reservoir, composite culture (poly culture) of different fish species are commonly used. Combination of phytoplantivorous, zooplanctivorous, omnivorous species which feed on different stratum such as surface, water column and bottom are used to optimize the effective use of available food in reservoirs. Also in CBF energy is minimally used. There are no mechanized boats used in reservoirs. All vessels operated in reservoirs are canoes and uses of mechanized motor boats are prohibited in reservoirs. Fish harvesting is mainly done using gill nets in CBF in minor perennial reservoirs and dragnets are being operated in seasonal reservoirs at the end of the culture cycle. As such no fuel or energy is used in grow out period as well as in fish harvesting in the seasonal reservoir CBF in Sri Lanka.

Area of reservoirs can vary from five hectare to sixty hectares and there are around 12,000 such functioning reserves available in Sri Lanka. The yields of the reservoirs vary from 52 kg ha^{-1} to 1801 kg ha^{-1} and mean production was reported as 450 kg ha^{-1} (Wijenayake et al., 2005). Table 4 indicates the reservoir area and yield of some seasonal reservoirs in five administrative districts of Sri Lanka.

Table 4. Reservoir area at full capacity (ha) and effective reservoir area (ha) (in seasonal reservoirs effective reservoir area is considered as the half of the reservoir as the reservoirs are drying off after 6-8 months) and fish yield kg ha^{-1}.

District	Name of reservoir	Total area (ha)	Effective area (ha)	Yield (ha^{-1})
Anuradhapura	Bulankulama	10	5	353
	Gambirigass wewa	17	8.5	127
	Karambegama	9	4.5	53
	Katugampolagama	17	8.5	243
	Pahala	21	10.5	195
	Sandanamkulama			
Kurunegala		10	5	205
	Kumbalporuwa	10	5	643
	Kekunawa	9	4.5	527
	Pahala Wewa	21	10.5	120
	Wawulewa	29	14.5	56
	Mataluwawa			
Hambantota		22	11	54
	Gonnoruwa	13	6.5	377
	Kudaindi Wewa	11	5.5	710
	Lunuweraniya	17	8.5	72
	Madagamkadawara	5	1.5	276
	Palujandura	3	3	1801
	Swodagama	6	9.5	373
	Weliwewa	19		182
	Wewegama		7	
Monaragala		14	6.5	1514
	Dosar wewa	13	8	623
	Bodagama wewa	16	10.5	248
	Galwale wewa	21	4.5	716
	Meegass wewa	9		877
	Mahagalara			

Chapter 4 – Socio-Economic Vulnerability Analysis

CBF farmers in Seasonal reservoirs are mainly depending on the agriculture as their main income avenue. CBF is a supplementary income for rural communities. Although it is a supplementary income, CBF provides significant contribution to economy of paddy farmers. Also it creates part time job opportunities and provides easy access to animal protein in affordable price to other community members assuring food security and nutritional security. CBF provides benefits to the faming society in different ways; increase savings in the funds of farmer organization, provide capital to organize social activities such as rehabilitation of irrigation cannels and reservoir, organizing welfare activates in the community and some farmer communities have started loan schemes for community members.

Possible impacts of changes in rainfall regimes and prolonged drought:

Impacts on inland surface waters:

- Changes in rainfall regimes and more prolonged droughts in the Dry Zone areas could lead to greater evapotranspiration which could impact on the inland fishery.
- Increased flooding due to increasing number of high rainfall events will affect inland aquaculture and capture fishery due to pollution, sedimentation and any adverse changes in water quality parameters of surface water bodies (mainly tanks) that sustain this fishery.
- Drought would lead to lower yields in seasonal tanks, and thereby have severe impacts on the inland fishery as investments for aquaculture may not yield adequate returns (Anon., 2010).

Impacts on rural communities:

- Reduced production from the inland fishery would affect rural nutrition and incomes for those dependent on this activity (Anon., 2010).

Possible impact of rising temperature:

- Inland wetlands important for the food fishery may be adversely affected by temperature anomalies with resultant changes in water quality that could cause fish kills. (Anon., 2010).

Impacts on inland fish stocks:

- A temperature rise of about 2°C may have substantial impacts on the distribution, growth and reproduction of fish stocks – in both marine and inland waters.
- Rising temperatures may also lead to changes in spawning areas and distribution patterns of commercially important fish stocks.
- Decreased primary productivity caused by temperature anomalies can affect the abundance of species higher up in the food chain in the long-term.
- Rising temperatures may also lead to greater evapotranspiration/evaporation in irrigation tanks which may have impacts on the inland fishery and aquaculture.
- There could be temperature related sex change in some fish species, with resultant gender imbalance and resultant depletion of fish stocks. This could especially affect aquaculture (Anon., 2010).

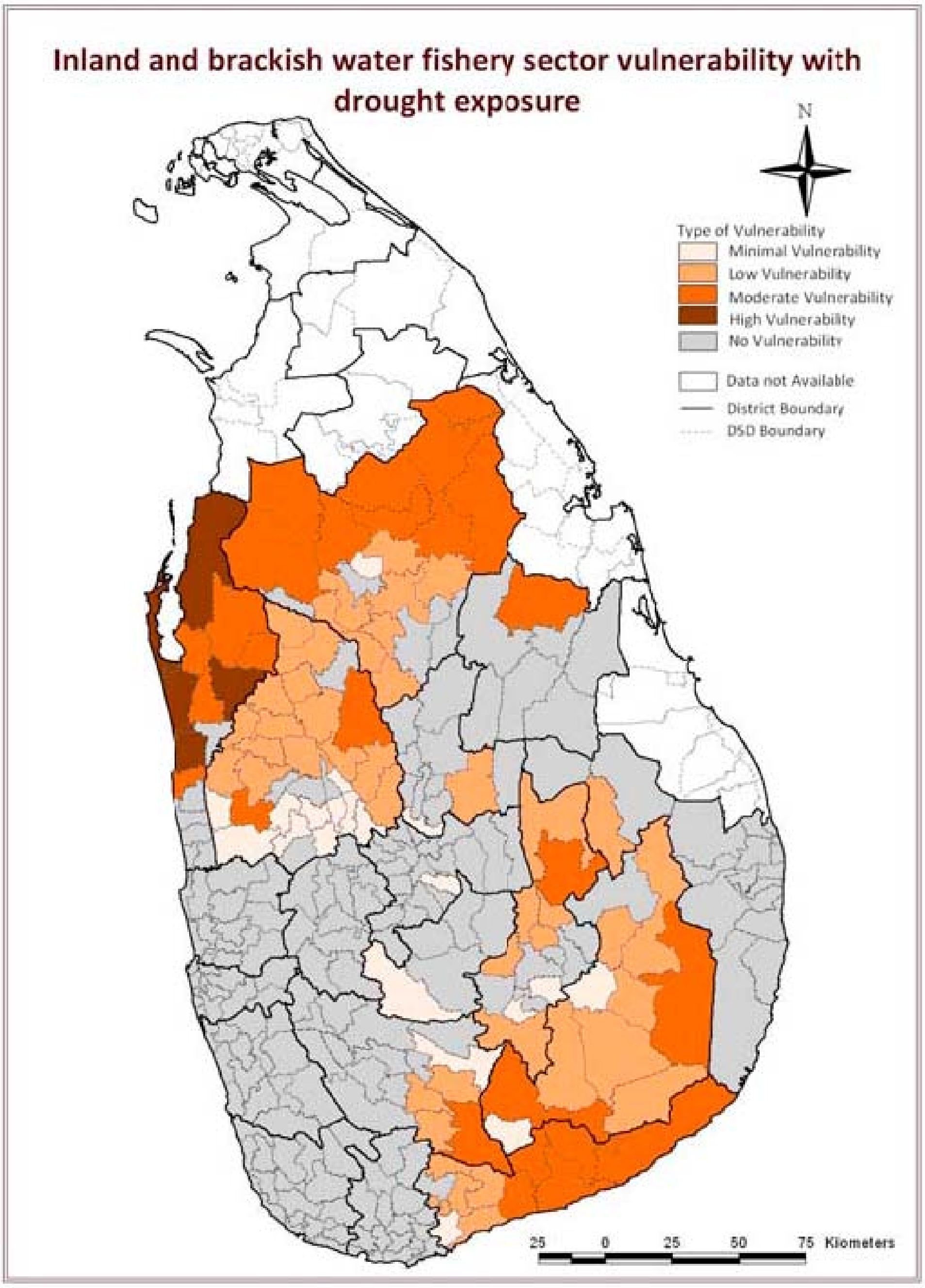


Figure 8. Vulnerability of the inland/brackish water fishery sector to drought exposure (Anon, 2010)

Vulnerability to drought exposure in the inland and brackish water fishery sector is widespread, particularly in the Dry and Intermediate zones (Anon., 2010) (Figure 8).

Chapter 5 –Policy options

(1) Long term simulation of water volumes of seasonal reservoirs and those associated in the cascades should be combined with other models to predict reservoir filling patterns.
Vulnerable reservoirs for the early drying out due to changes in rainfall pattern can be earmarked by using historical analysis of water level fluctuations.
It can be used to rank the reservoirs, which have high vulnerability for climate change impacts and less vulnerability for climate change impact. Accordingly priority for stocking can be given for the less vulnerable reservoirs.

(2) Climate change has shifted the filling pattern of the seasonal reservoirs so that changes in stocking pattern are needed in culture based fisheries.

(3) Current analysis has shown that the reservoirs have reached full capacity in the period of September-November in most reservoirs. However farmers are reluctant to stock fish in reservoirs until spilling off has completed. If fish can be stocked in cages in the reservoir and release them after spilling off the reservoir, extra two-three month can be added to the culture period, where reservoirs have shifted drawdown.

(4) Alternative means of stocking fish fingerlings reared by rural communities should be sought. Hence, harmonization of agricultural and CBF activities in non-perennial reservoirs as well as in seasonal reservoirs, depending on the water availability is recommended to improve climate change adaptations of rural communities.

(5) Improved water management strategies should be adapted by the paddy farming communities to improve the water retention in reservoirs. Therefore, managerial decisions for CBF should be taken at the "Kanna Meeting" (seasonal meting conducted by paddy farming community before starting the cropping cycle). Close communication with government institutions directly involved in water management and aquaculture such as Department of Agrarian Development and National Aquaculture Development Authority would be helpful for communities to have good managerial practices.

(6) Identification of alternative stocking sources (perennial reservoirs, minor perennial reservoirs, fish pods etc.) for produced fingerlings for instances where the seasonal tanks are not filled on time.

(7) Improvement of value addition and product development for harvested fish would be an alternative to overcome marketing problems of less grown fish species. Capacity building in the postharvest processing and value addition can draw the attention of woman to CBF activities and improve the household income of vulnerable communities.

- **Existing stakeholder interactions**

Institutional links between the culture-based fisheries in seasonal reservoirs of Sri Lanka is given in Figure 9. National Aquaculture Development Authority of Sri Lanka (NAQDA) is responsible for the aquaculture extension in the country. NAQDA has regional aquaculture extension officer and aquaculture extension offices (AEOs) in each district. AEOs are directly communicated with the farming communities and they transfer technical knowledge as well as coordinate between NAQDA and FAOs. AEOs are helping farmer organizations (FAOs) to find fingerlings required to stock in reservoirs. Based on the farmers' requests, AEOs make arrangement to purchase fingerlings from regional Aquaculture Development Centres (fish breeding centres) and fry-fingerling rearers. Also NAQDA issues aquaculture licences to farmer communities/aquaculturists through AEOs. Department of Agrarian Development (DAD) has the authority of water management and decision making in paddy cultivation collaboratively with FAOs. DAD is involving in the planning of agriculture and aquaculture in "Kanna meetings" (Seasonal meeting for planning agriculture activities for two paddy farming cycles) as they are responsible for the management of irrigation to paddy lands.

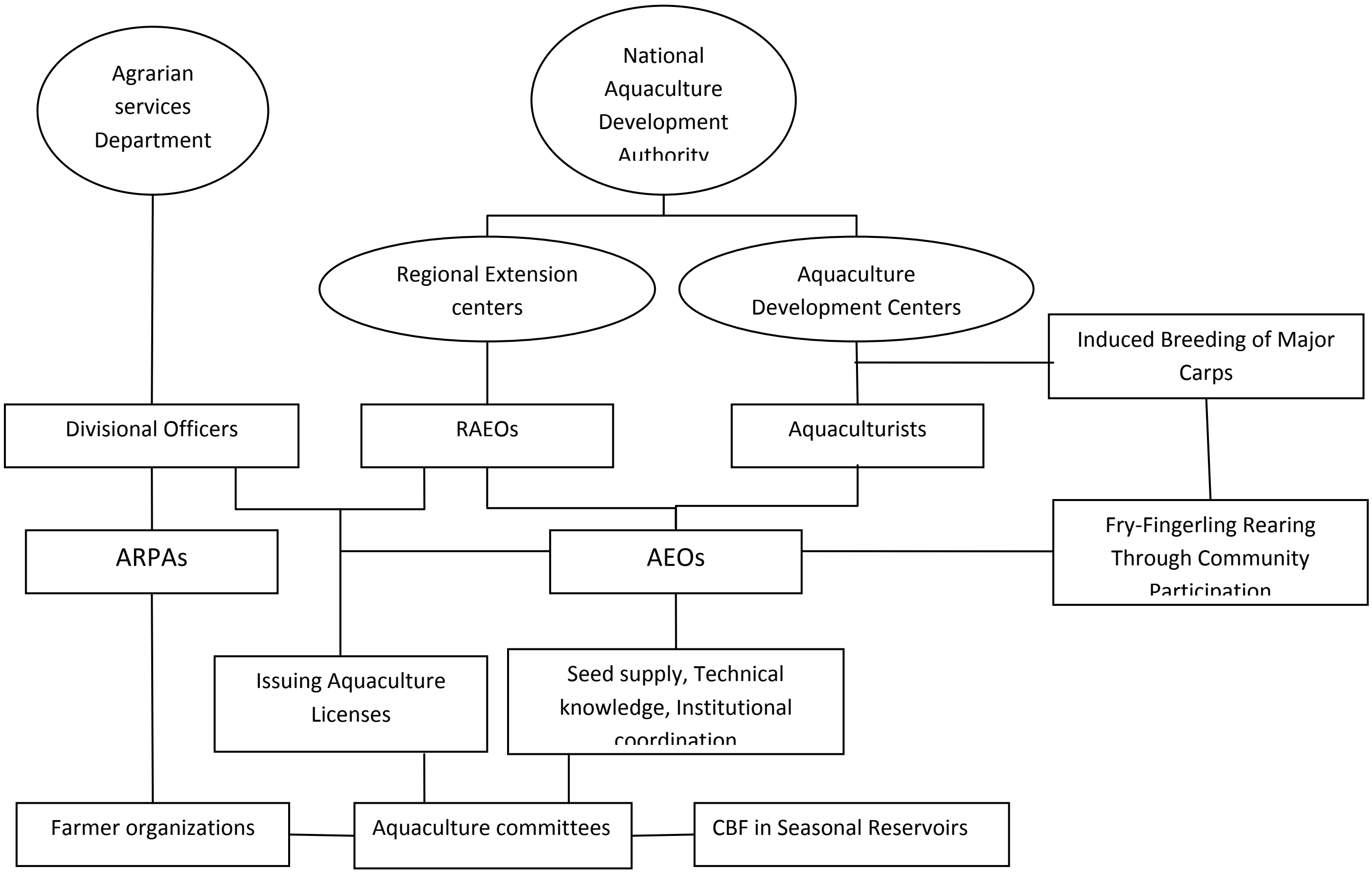


Figure 9. Institutional links between the culture-based fisheries in seasonal reservoirs of Sri Lanka (adopted from Amarasinghe, 2006). RAEO- Regional Aquaculture Extension Officers, AEO- Aquaculture extension officer, ARPA- Agrarian Research and Production Assistant.

Chapter 6 – Summary and Action Plan

- **Prediction of water availability and risk assessment**

Reservoir filling patterns and water availability should be predicted to plan the CBF. Meteorological Department, NAQDA, NARA, Department of Agrarian Development, Department of irrigation and Universities have to be involved in developing a suitable methodology to predict the water availability under the scenario of climate change. Based on the predictions, planning of CBF should be adapted. Suitable reservoirs under climate change should be identified and priorities will be given to the most suitable reservoirs to ensure the sustainability of the CBF.

There is a need of risk assessment on CBF in future climate change implications. It would be helpful to develop an insurance scheme for CBF in Sri Lanka. This will encourage people to invest in CBF under climate change scenario and minimise the risk on their investment. Also based on the risk assessment, different strategies can be adapted to minimise the impacts and can support the sustainable development of CBF in seasonal reservoirs. The risk assessment system would be made through collective decision making approach and the method should be identified by the farmer communities and grassroots level officers those who are directly involved in decision making in CBF. It would be difficult to adapt common strategies to the entire country as different intensities and impacts are reported from region to region.

- **Need to increase awareness and capacity building**

Improving knowledge base of climate change impacts in the world has identified as a key factor to recognize the adaptations for vulnerable communities. Therefore, knowledge on changing climate and current adaptations and future strategies has to be studied and awareness and capacity building in relevant authorities should be adapted. Intensity of the climate change impact on vulnerable communities can be minimised through effective knowledge transferring mechanism, which can be readily available and easily reached by the all stockholders in the seasonal reservoirs who are practising CBF. Improving awareness on climate change impact adaptations and mitigations should be taken as a national concern and necessary strategies should be adapted to disseminate important information. Through effective communication, all the stakeholders can be triggered out to prepare for climate change impacts. Effective knowledge transferring can use to motivate farming communities to analyse the existing issues and adaptations for climate change and can prepare them for the future changes.

Capacity building in the extension services to predict forth coming changes and shearing knowledge effectively in advance with the communities should be facilitated. Also proper mechanism of collecting necessary field information, which are important in future climate change predictions should be collected with the participation of community members i.e. regular measuring of water level, volume of water release for agriculture, rainfall etc. Capacity building in scientific researches on climate change impacts should be adapted to identify strategies to mitigate the impacts. Capacity building in community level should be implemented, when new technologies are introduced i.e., value addition techniques (Figure 10).

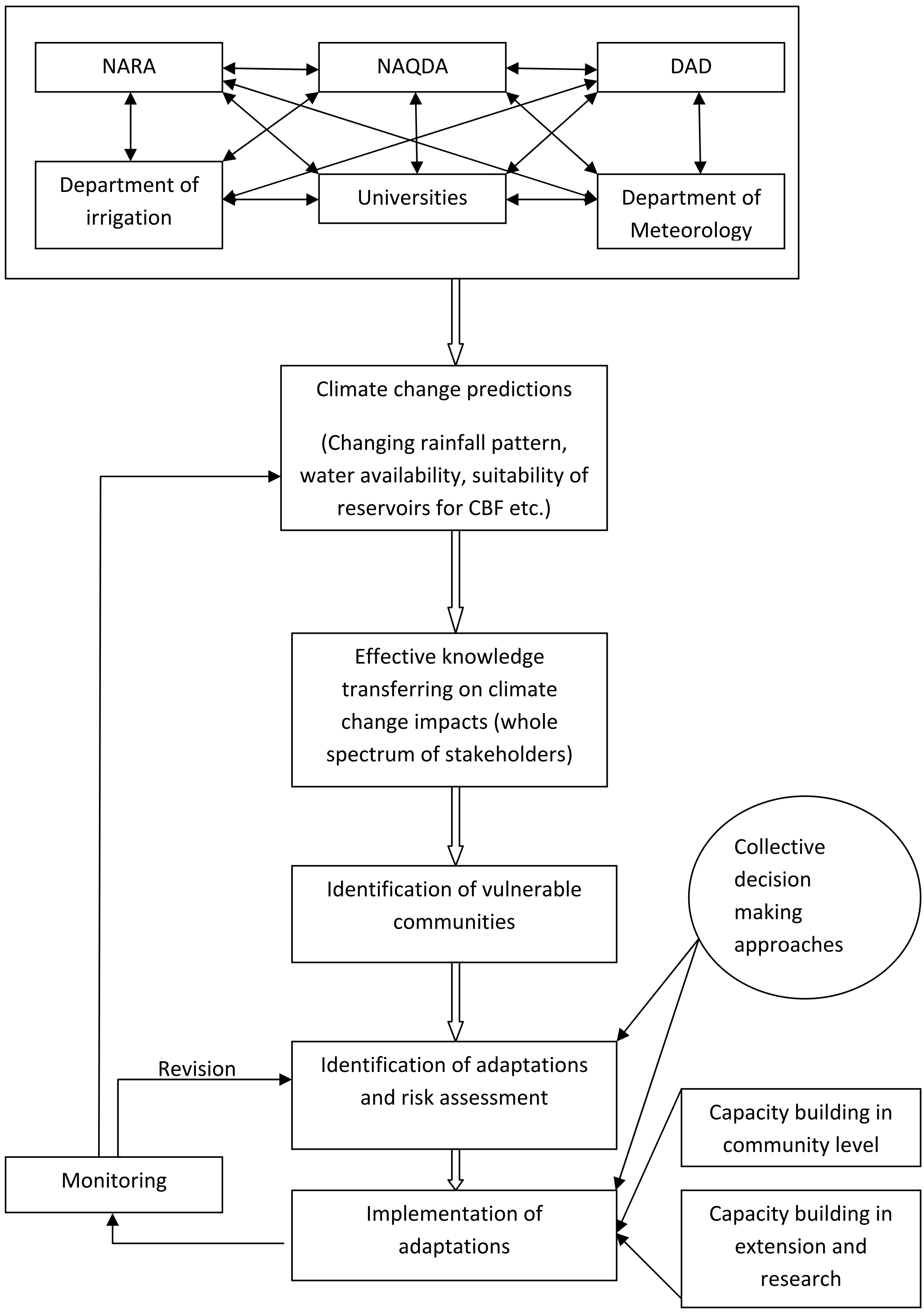


Figure 10. Schematic diagram of action plan for adapting climate change impacts on CBF in seasonal reservoirs in Sri Lanka.

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